Digital Infrared Photography for Mapping Insect and Disease Stress in Piñon Pine
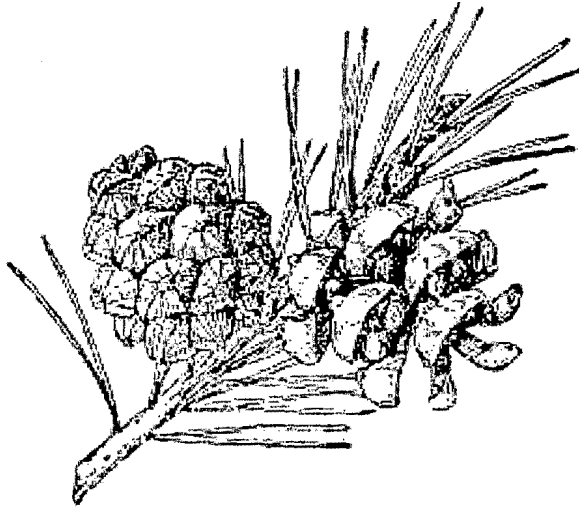
by:
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Remote Sensing and GIS Program
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Final Report

Digital Infrared Photography
for Mapping Insect and Disease
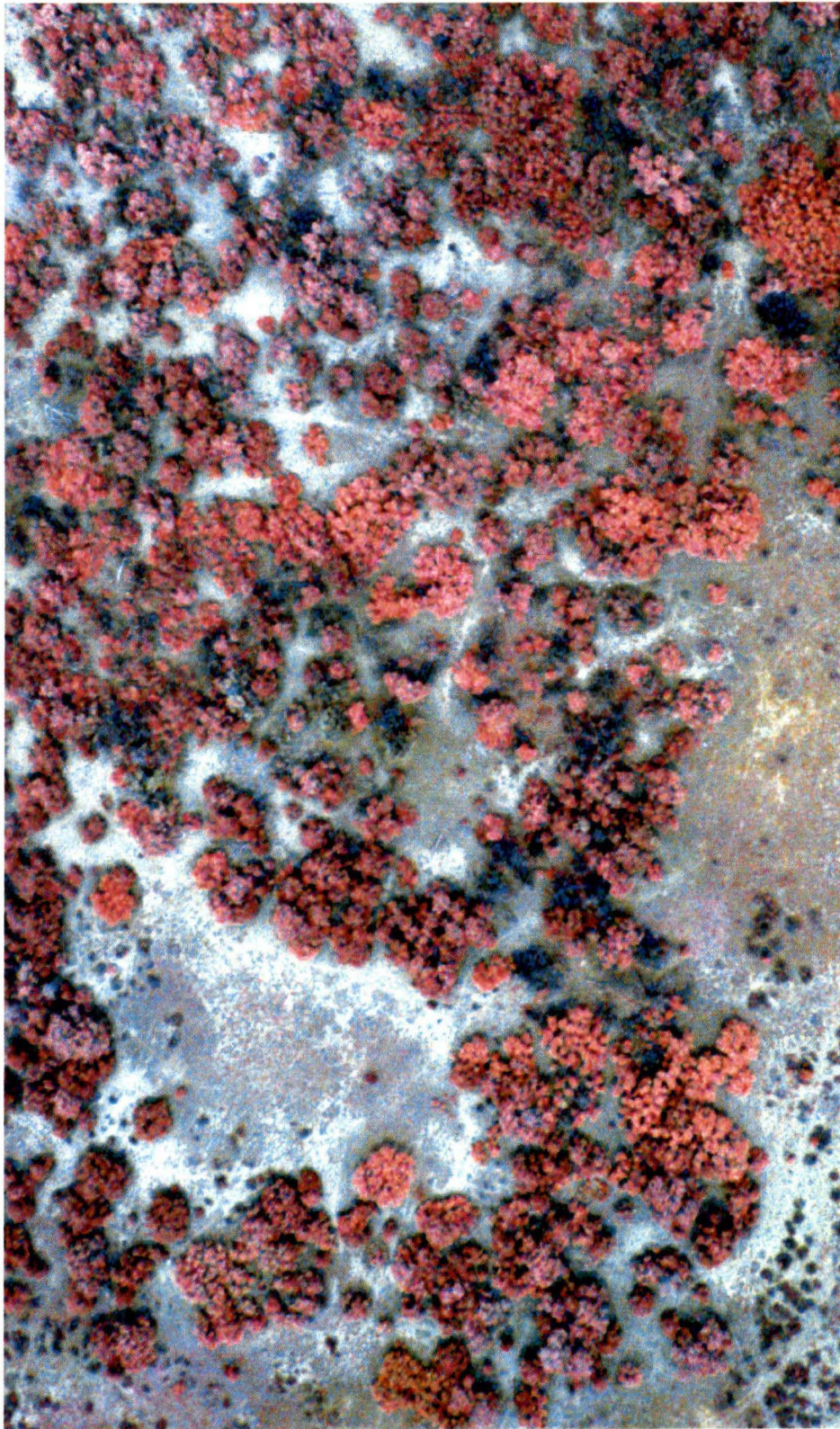# Stress in Piñon Pine

Submitted to:
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Frontispiece: Digital Color Infrared Image

Acknowledgments

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1   INTRODUCTION

The USDA Forest Service entered into a cooperative agreement with Colorado State University to analyze and compare conventional aerial color infrared photography and digital color infrared imagery from a Kodak DCS420ir digital camera flown in Southwestern Colorado. The semi-arid woodland includes *Pinus edulis* (piñon pine), *Juniperus scopulorum* (Rocky Mountain Juniper) and *Juniperus osteosperma* (Utah Juniper). The study site has been investigated by biologists and entomologists for black stain root disease and *Ips confusus* beetle attacks resulting in widespread piñon mortality. The main focus of the study is to determine if pre-visual stress, fading and mortality can be accurately assessed from the imagery, and to document the technology and procedures needed for image analysis.

2   OBJECTIVES

Project objectives may be summarized as follows: (1) Determine the capability of Digital Color Infrared Photography (DCIR) to detect piñon pine stress from *Ips* bark beetles or black stain root disease, (2) Determine the effectiveness of DCIR, in comparison to conventional color infrared photography (CIR), for detection of infested trees, (3) Define the earliest stage of stress that can be detected using DCIR, (4) Determine the potential effectiveness for using computer-aided analysis techniques to identify and map infested trees, and (5) Document appropriate automated computer processing techniques for mapping the location of mortality and stress.

3   METHODS

3.1   Overview

To determine the capability of Digital Color Infrared Photography (DCIR) to detect *Pinus edulis* (piñon pine) stress, the areas around transects established by Holly Kearns in a 1999 study of the McPhee Reservoir area (Kearns, 2001), were examined with ground visits and image samples. Two kinds of photography were available, both taken in 1998. Site visits were made three years later in 2001. Frames of conventional Color Infrared (CIR) transparencies and DCIR photography were chosen for overlap with the biological transects. Individual trees in various health states were compared on the images. Site visits collected current tree health conditions and ground control data. Current tree crown health was compared to the image condition to document trees that had begun fading, or were dead. An attempt was made to detect early stages of stress in piñon, and image processing techniques designed to highlight stressed trees were investigated. To support these objectives, a spatially explicit site Geographic Information System (GIS) dataset was produced, both for navigation and to serve as a collection utility for the various types of imagery and supplemental information. GIS coverages available from the USGS and

Forest Service were included for gross orientation, vehicular access, and to serve as a link from images to conventional mapped products. Conversion to digital format was helpful for the CIR transparencies. These were digitally scanned to produce image files for analysis, and were compared qualitatively to the original format transparencies and DCIR images. DCIR and CIR images were spatially oriented with GPS and rectified for inclusion in the GIS. Most of this information was used to drive an iterative classification effort that identified general vegetation patterns, piñon crowns and attempted to detect stressed piñon pine trees.

In summary form, the following generalized steps were implemented in order to meet the stated objectives of the project. For complete information, see Hayes (2002).

- Create aids for study site navigation, such as subsets of topographic maps and raw images
- Collect GPS data for image rectification, navigation and fading piñon trees
- Plot GPS data on images for locating transects and previously defined mortality perimeters
- Locate the perimeter of DCIR images and establish relation to each other
- Choose study images
- Compare CIR and DCIR to each other, in the context of field inspection
- Collect vegetation species and condition data, especially yellow, fading or newly killed piñon on DCIR images
- Differentiate vegetation types on DCIR to isolate and identify stressed piñon
- Relate field identified stressed piñon signatures back to DCIR imagery
- Attempt to identify a piñon stress signature in DCIR images with computer aided image processing
- Verify that stressed piñon in the June 1998 DCIR are indeed dead or fading now
- Describe accuracy of vegetation classification and identification
- Document image analysis techniques
- Produce classified images to demonstrate the results
- Describe GIS used to warehouse the information for the project, and present the results

3.2 Aerial Photography

Two kinds of photography have been provided for the study, conventional color infrared transparencies and computer image files produced with a digital camera.

3.2.1 Conventional Aerial Photography

9X9 inch Kodak 2443 CIR Aerochorome II transparency film (CIR) was acquired on August 19, 1998 by the Forest Health Technology Enterprise Team. (See Kodak, 2000 for more information on this film) A Zeiss RMK A 21/23 mapping camera was used. Flight lines were regularly spaced in North-South directions. The film itself is sensitive to 250 - 900 nm wavelengths, but is limited on the lower end to 510 nm with a yellow Wratten #12 filter. Acquisition altitude was 3,475 m (11,400 feet) above Mean Sea Level (MSL), and Barry Russell was the photographer in a King Air photoplane. The

ground elevation is between 2,100 and 2,225 m (6,900 and 7,300 feet) at the selected study sites. Average height flown above ground level was approximately 1,310 m (4,300 feet). Camera focal length was 210 mm (8.25 inches) This resulted in an average scale of 1:6,254 (1:6,000). Several analysts familiar with aerial imagery reviewed transparencies of the site, and agreed that the images were exposed correctly, but noted that to capture the best detail in tree canopies, it is necessary to choose an exposure that tends to overexpose soil conditions.

3.2.2 Digital Aerial Photography

A Kodak DCS420ir digital camera was used to acquire Digital Color Infrared photography (DCIR) over a smaller part of the McPhee Reservoir area, during June 1998. (See Figure 1) This type of photography was acquired over the Kearns study plots, including the west side of the Reservoir, north of the flooded 'Sage Hen Flats' area.

Images were taken vertically at approximately 305 to 915 m (1,000 to 3,000 feet) Above Ground Level (AGL). The higher altitude imagery was acquired in the mid to late afternoon, but was severely mottled with cloud shadow. These frames include large amounts of 'shadow edge', and have not been used for analysis. Some of the lowest altitude images were blurry. The low altitude images are exceptionally detailed, and were chosen for study. The lens was a 28mm focal length model supplied with the camera. (This is equivalent to 73mm focal length if compared to a normal 35mm camera imaging area) Eric Johnson was the navigator and Tom Eager was the photographer.

Scene to scene differences in resolution exist due to the low flying height and sloping character of the terrain. Point resolution varies with flight line altitude and ground topography, but is approximately 10 and 15 cm (4 and 6 inches) in the low altitude images. When scale is calculated as focal length / height above ground, then the imagery used has a point scale ranging from approximately 1:10,900 to 1:16,300.

Figure 1 DCS 420 Infrared Camera

Six lines were flown. Several of these were only partially photographed. Image overlap was not consistent due to manual triggering of the camera, however, the photographer was able to obtain more imagery over areas of interest. Exact flight lines are not available due to GPS cabling failure. (Personal communications with Tom Eager, Paul Ishikawa, Jim Ellenwood, 2001) GPS interface issues have been improved since this time. (Hinkley, 1998)

Computer image files from the mission were supplied by the USFS Lakewood, Colorado Service Center. Files are produced by the camera as proprietary 36 bit color images, and

then converted to 24 bit data by Adobe Photoshop, and Kodak software 'plug-ins', for import to image processing software. This data is saved first as Kodak proprietary format 1.6 Mb files, then was converted to 4.3 Mb .TIFF file format. If an LZW (Lempel Ziv Welch) compression license has been purchased, these may be further reduced to about 1.4 MB per photo for storage and archive. (FHTET, 1996, Kodak, 1999) This lossless format is suitable for archiving images, and does not alter the 24-bit data.

Lens Filter

The DCS420ir CCD can image wavelengths in the green and red portion of the visible spectrum, and into the near-infrared frequencies. An external lens filter is used to block blue wavelength light on the lower end of the spectrum, and reduces CCD sensor oversaturation in the upper end of the near-infrared. The camera was fitted with an Omega Optical 650 BP300 yellow filter. Figure 2 is a transmittance curve furnished by Omega Optical, the original equipment manufacturer. This bandpass filter serves as a 'blue blocker' for the short wavelengths, and limits the upper portion of the infrared wavelengths reaching the sensor. (Paul Ishikawa, personal communication) This has been found to work well for natural resource applications (Bobbe, Zigadlo, 1995). Exact radiometric profiling for the entire camera system is not available from the manufacturer. A 'yellow' Omega Optical 650 BP300 lens filter was used, and limited the sensed wavelengths to 510 - 800nm.
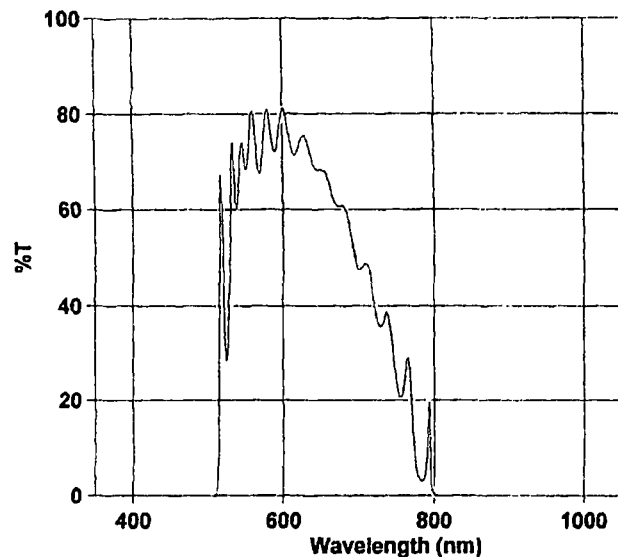
Figure 2 Lens filter transmission curve

3.3 Geographic Information System

The boundaries between image processing and Geographic Information System (GIS) development are often blurred. When an image is georeferenced, a complementary and cyclic relationship may be developed. Images are used in the field to gather positional and feature data. This information can be used to categorize or classify the image for further use, and position the image spatially. Back in the field, these enhanced images can be used to gather additional spatial data. Added to the GIS development cycle, they may be combined or overlayed with other digital products such as road coverages and Digital Orthophotograph Quadrangles (DOQs). The enhanced imagery may be used to find occurrences of conditions in parts of the image not previously sampled. Models may be applied to the digital layers of information to bring out unique types of information, determine proximity, create new information groupings, and apply spatial statistics. In this way, the GIS grows cyclically and can be used as much more than a limited set of

images and maps. For examples of other GIS and remote sensing applications, see Lachowski, et. al., (1996) and Fisk, et. al. (1998).

One study similar to this one found that an image processing model could effectively map beetle infested *Pinus taeda* (loblolly pine) from video data. First, tree color characteristics were identified in video imagery that indicate southern pine beetle damage. This was accomplished by recognizing that infested trees had a lower level of green reflectance, and increased red. A simple band differencing algorithm was successfully used to find pixels indicating damage. Pixels were then buffered and clumped, using edge detection to delineate the outline of affected tree groups. (Hoffer, Linden, Paschke, 1995) Similar methodology proved to be helpful in analyzing the DCIR images provided of the McPhee area.

Supplemental Geographic Information System (GIS) coverages were utilized where available from the San Juan National Forest (SJNF). Examples include road, public land system (township and range) section lines, federal/private ownership boundaries, hydrography and hypsography. These supplementary coverages were 'clipped' from UTM zone 13 master coverages, using the boundary of the Trimble Point quadrangle. Zone 13 coverages were reprojected into Zone 12 with ESRI *Arc/Info®*. Other areas were prepared to specification as requested to support cooperating researcher's needs.

As the investigation progressed, digital layers were collected in CSU College of Natural Resource computer system file directories. Cumulative information on the site was maintained in an *ArcView* 'project'. (See Plate 1) This GIS project file provided visually and spatially organized access to all collected materials that have been geo-referenced and are in UTM Zone 12 projection. Files were stored in UNIX protected file directories accessible by ERDAS *Imagine®*, *Arc/Info*, and ESRI *ArcView®* software. File formats were selected that provided the most global access by several complementary software packages. A list of some useful spatial data layers included: GPS data provided by the biologic researchers including GPS points representing plot centers, Ground Control Points (GCPs), mortality polygons, and mortality points. Other coverages modified or created included rectified Digital Color Infrared (DCIR) images, Digital Orthophoto Quarter Quadrangles (DOQQs) for backdrop images, Digital Elevation Model (DEM) data, text files for documentation and processing, classified images, and supplementary GIS coverages mentioned above.

Development Cycle

To develop these data layers, several interrelated image processing and GIS software packages were used to cyclically develop the GIS. Trimble *Pathfinder Office®* was the initial software for handling the GPS data. It was used to download, differentially correct, and group the individual fixes provided by Kearns to create point, line and polygon features. It was then used to prepare export files for *Arc/Info* processing. *ArcView* was used to organize and print tables of GPS information. These were stored as ASCII files, for field navigation, archive, and for input to the rectification process.

Coordinate locations visible on the DOQQ, CIR and DCIR imagery were used for rectification of imagery. DCIR imagery was rectified using well-dispersed GPS points as ground control. These points were added to the navigation point file. Suitable GCPs were found at road intersections, fence lines, isolated rocky material, and the south edge of well defined vegetation. ERDAS *Imagine* was used to rectify images with these GCPs. This facilitated site navigation and allowed GPS field data collection of fading trees, even when the location was not easily found on the imagery among other vegetation.

The rectified images were added to the GIS and overlayed to make improved orienteering maps using *ArcView*. These maps made use of the supplementary GIS coverages, GPS coordinates, and cartographic features. Reading the *Arc/Info* files directly in some cases, reference maps were designed incorporating GIS files from the USGS and the San Juan National Forest, and then were displayed as images on a computer monitor, saved as printable files, or printed. Printed maps were used in the field to collect data. As new data were collected, they were put into the GIS to produce more complete map and image products. The *ArcView* project provided an interactive spatial database for coordinating the study. At any time, the most up-to-date version was available to be utilized in presentations, illustrations, for field use, or to give to other research personnel.

3.4 Field Work

3.4.1 Overview

Study sites for this project surround three of the 22 research plots investigated by Kearns (2001) at McPhee Reservoir in 1999. These locations are in the area formerly known as 'Sage Hen Flats', which has been mostly flooded by the creation of the reservoir pool. (See Figure 3) Line of sight visibility is limited in the woodlands. The study sites are on southwest to southeast exposures. They were visited on four trips in 2001 to gather reference data to complement the biologic transects and plots.
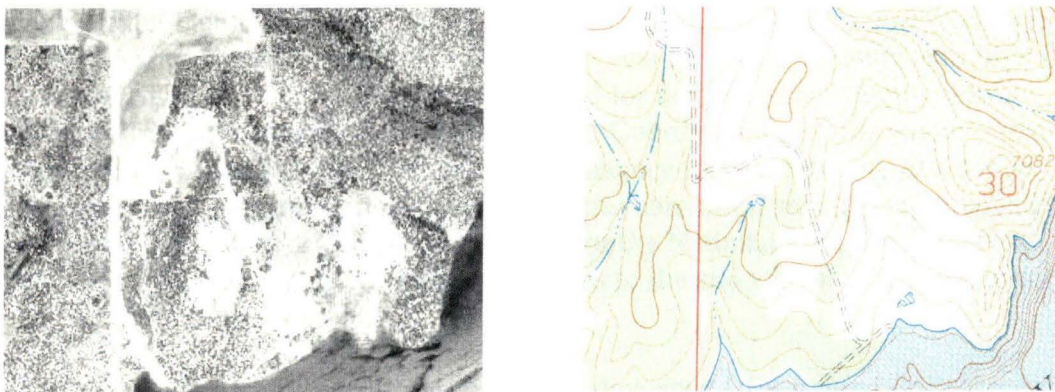

Figure 3 Portion of Digital Orthophoto Quarter Quadrangle and 1:24,000 Topographic Map

A number of orientation materials were available. Standard USGS 7.5-minute maps, Digital Orthophoto Quarter Quadrangle (DOQQ) black and white images, and GPS data

was furnished by previous research efforts. Conventional color infrared transparencies (CIR) of the vicinity, and digital color infrared images (DCIR) had been acquired from a Kodak DCS420 camera in 1998.

On the first trip, GPS locations were defined to use as Ground Control Points (GCPs) for image rectification, and crown observations were begun. A second trip was made after some DCIR images were rectified, and additional observations were made. Spatially accurate DCIR paper prints were used to attempt to locate individual trees on the Kearns transects. Notations were made directly on laminated image copies, recording conditions that existed at identifiable locations. Trees crowns were observed for color and health changes to support computer image analysis. Pictures were taken to document unusual conditions, and to provide high quality imagery for presentation. A third and fourth trip were made to check the accuracy of the image analysis classifications.

3.4.2   Global Positioning System Use

Vehicular access to the study area is limited in the winter months. The camping area is about 2km away, and overland travel is needed at times to reach the sites. A compass and small hand-held Garmin E-Trex GPS unit helped with navigation while hiking to the sites.

Holly Kearns provided partially processed plot center and polygon location data from the 1999 biological study. Approximately 55 individual GPS 'fixes' were used in each point feature acquired. Positional Dilution of Precision values (PDOPs) were masked to less than 8 by firmware in the unit. These parameters are sufficient for field use.

A Trimble GeoExplorer II, similar to the one Kearns used, was furnished by the CSU Department of Forest Sciences. It came with extra batteries, Pathfinder Office software v2.51, a download cable and battery charger. This is considered a high-quality resource grade receiver.

High quality GPS setup parameters were used when collecting new GPS data, to ensure reliable position data in the dense woodland environment, and to help overlay image products. Positional Dilution of Precision (PDOP) values of 6.0 or lower, and Signal to Noise Ratio (SNR) of 6.0 or higher, were selected for the firmware filtering masks. A minimum of 180 points were collected for GCPs. Coordinate locations were determined at points visible on the DOQQ, CIR and DCIR imagery for rectification, navigation, and final accuracy assessments of imagery. Differential correction was applied to all GPS data collected using the Fort Lewis base station, or the National Park Service Mesa Verde station. These were the two closest stations to the site which collect correction data on a regular basis.

DCIR imagery was carefully rectified using well dispersed GPS ground control points (GCPs). Suitable (GCPs) were found at road intersections, fence lines, isolated rocky material, or the south edge of well defined vegetation. At least six points were taken for each DCIR image used in analysis. These points were as close to the corners, and across the middle, as possible, to correct for aircraft motion affects. This facilitated site

navigation, and allowed GPS field data collection of specific features of interest, even when the location was not easily identified on the imagery.

GPS Processing Details

A grouping feature within *Pathfinder Office* software creates polygon and point features from simple GPS files. These represent mortality perimeter polygons, or plot centers, which are the originating end of the biologic transects. Simple output maps were made to visually check for complete data, and to use for early orientation visits to the site. The last step in GPS file preparation is using the export feature. It prepares a set of three export files, used by the GIS program *Arc/Info*, to generate cartographic objects. Export creates a file for the point groups, a metadata file, and a file that is used as a program to facilitate the transfer. The cartographic objects may represent lines, points or polygons.

The three types of files exported from *Pathfinder Office* are used together in the preparation of an *Arc* coverage. The first file is an Arc Macro Language (AML) program that coordinates the creation of a GIS cartographic coverage. It makes a new coverage with the point groups, and appends the metadata file. This new GIS coverage was enhanced with additional cartographic metadata including projection and spheroid, then edited. AML editing programs were utilized to selectively remove sliver polygons found earlier. Holly Kearns supervised this procedure to ensure faithful adherence to the intent of the polygon boundaries. Only minor corrections of a few meters were required in most cases; and several lines were subjectively inserted to geometrically close open features intended to be polygons. An additional benefit of using *Arc* is that the files can be read directly, imported or exported to nearly any modern GIS or statistical software package.

Supplemental Ground Level Photography

Hand held 35mm color print and color slide photographs were taken with a Canon AE-1 camera for visual orientation to the site environment. Common soil surface conditions, tree, shrub and grasses found in the area were captured. Large ungulate and human effects on soil and vegetation, such as grazing and vehicle traffic, were noted on film. Scanned pictures of erosion, common diseases of vegetation, and site markers were acquired for future presentations. GPS locations were acquired at some of these photopoints for inclusion in the GIS.

3.4.3 Collection of Tree Species and Condition Data

Ten digital color infrared (DCIR) images were selected for field checking. Images were chosen that were clustered near biologic study plots, and frequently overlapped one another. Crown foliage masses were viewed from ground level by eye, and notations made on the laminated images as to the species and condition of the crown mass. No attempt was made to determine the number of individual stems making up the crown mass, since stems are not visible in the imagery, nor is it clear from which stem foliage may arise. For the purposes of field counts, an 'observation' consists of a circled symbol on laminated imagery which represents the species and condition of a portion of the crown mass. An observation should not be considered to be a single tree, as multiple stems frequently compose a crown mass, and other species may intermix with portions of the crown mass outside the observation perimeter.

All sizes of trees seen in the images were sampled. The smallest size apparent in this particular printed imagery was about a meter across. A better printer, or better paper would have provided more detail. Larger trees often have fractured crown masses, and were sometimes difficult to identify as a single source. They were counted as a single observation when the source was clear.

Several types of additional notes were made on the field images. Mixed crowns and dense thickets of vegetation were identified in places. Some notes on the composition of shrub and grass features were made, especially were they obscured or confused crown identification, but were not used directly in this study. Occasional mortality in juniper and other vegetation was noted on the images.

Individual crown condition notes were made for the trees that had discoloration. Crown condition counts were placed into one of three categories. The first, and most common class, was piñon with no obvious discoloration. Healthy juniper crowns were counted in the second class. The third class was piñon crown with any type of discoloration, from partial yellowing to fresh mortality.

Not all trees were inventoried. Dense vegetation was circled on foot, and openings in the forest were used for travel. A few steep slopes were avoided. Oak brush thickets were not usually crossed. Areas with dense young trees and little mortality were often ignored. Many areas were crisscrossed several times in the course of reaching distant study areas, and were much more thoroughly sampled. A few overlapping areas were even observed twice, with different routes and on different visits, but have not been double counted.

3.5   Image Processing

3.5.1   Digital Methods

ERDAS *Imagine* was the primary software for image analysis. A number of vegetation classifications were attempted with 'supervised' and 'unsupervised' techniques. Where image features are both known and are homogeneous, training polygons can be selected to represent some classes, and can be used to classify an image. This is known as a supervised classification and was one of the analysis techniques attempted. (ERDAS, 1997)

An unsupervised spectral classification technique was also attempted since this technique is suitable for the heterogeneous classification of highly textured vegetation and crown masses. This technique uses 'spectral grouping', and is discussed separately below. Once a data set was initially classified, coloration was chosen for each class to depict cover type identity. This created a thematic field checking map. Each pixel on a map represents an identified class, or in some cases, unknown pixels (and their locations) for ground inspection. Any color code could have been chosen, from realistic to high contrast. One possible color scheme found to be effective was: brown to indicate bare

soil, green to mark shrubs, red used for piñon, and blue for juniper. The high visibility colors of magenta, yellow and bright green were used to mark classes for field investigation, and black identified shadowed areas where little spectral information was available.

ArcView was used to create field mapping products, and medium quality printing was done on a large format Hewlett-Packard DesignJet 1050c inkjet printer provided by CSU. Each image was printed to a size of 26.5 x 40cm, and laminated.

DCIR imagery is a three channel data set, and each channel is a separate set of Digital Numbers (DNs). These sets of numbers were processed with computer algorithms found to be of use in enhancing the imagery to more easily identify stressed vegetation. These include Normalized Difference Vegetation Index (NDVI), red-green subtraction, and several kinds of ratio analysis. Each of these base image types were evaluated for the ability to find, or enhance, pre-visual and early stress in piñon. Due to the very small resolution elements in the DCIR images, low-pass filtering was evaluated to smooth the data and reduce the diversity of spectral response. This was intended to simplify the identification of classes, and reduce complexity. (Latty, 1981) A high-pass filter, or edge-detection algorithm, was evaluated to bring out the perimeter of crowns and mortality centers.

Spectral Grouping
Numeric analysis of DN values can provide a wealth of information from a suitable image file. Spectral grouping may be used to identify similar pixels for classification. Stratification may also be used to create levels in the data. Ranges of DN values may be reassigned new, or simplified values, to pool characteristics. An example might be to change those pixels with values below 20 in all bands, to zero, as a mask for shadow conditions. Another common technique is to mathematically cluster similar DN values and analyze them for spectral meaning.

Figure 4 is an illustration of three wavelength bands, in 8-bit format, used to cluster a sample of image data. If each group of data is representative of one feature class, then these class-clusters, or 'spectral signatures' may be used for identification. In this three-dimensional example, we see something similar to human analysis by eyesight, where the eye discriminates between classes based on the intensity of three bands. A red-green-blue monitor can show three-band data as an intuitive image in color. This analogy holds with a few bands; however, mathematically, any multi-dimensional band set could be used.
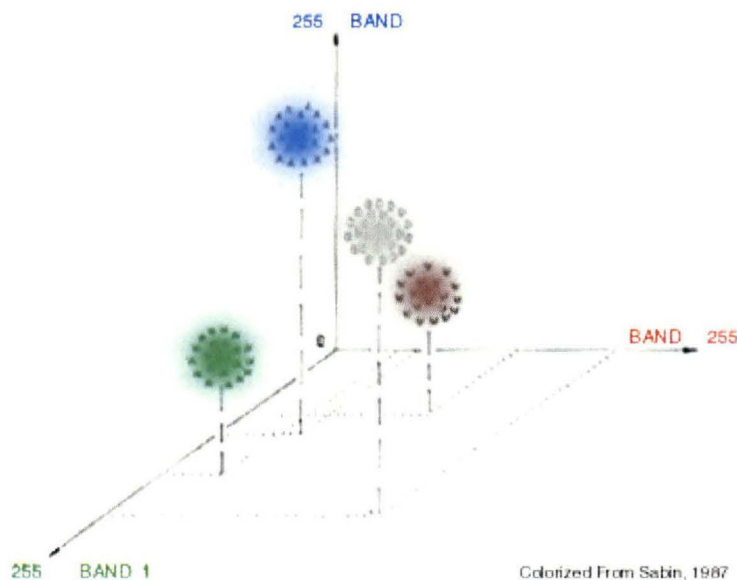
255   BAND

BAND   255

255   BAND 1

Colorized From Sabin, 1987

Figure 4 Spectral Grouping

The human eye processes multiple band sets poorly, and tends to be inconsistent. Where fine division of classes are needed, computer processing of imagery is faster, and does not suffer from the odd optical illusions produced by human vision. This is fortunate, since data is seldom as distinct as in the figure above. Classes of interest usually overlap, so class-clusters must be further divided and identified. (Jensen, 1996) John R. Jensen coined the term "cluster-busting" to describe this technique.

Classification By Cluster Busting

'Cluster-busting' is a computer facilitated procedure, where the multi-spectral space (multi-color, or multi-band) is first clustered (i.e. "unsupervised classification") and then selected cluster classes are further divided into sub-classes. This "unsupervised" technique is subjective in nature, and consists of the analyst selecting an arbitrary number of classes, and then investigating sub-classes of these, until the level of detail has been achieved. In each step, the analyst compares the spectral classes against known ground reference data, such as maps and photography, to identify the true character of each class. Those classes that emphasize the targets are then divided and analyzed in the same way, to narrow down and identify specific spectral signatures that identify the targets more exactly. A single target type may have several distinct signatures, such as the shaded and unshaded sides of a tree crown. Some classes will be representative of overlap, or mixed classes, and are either discarded, or subdivided. (ERDAS, 1997)

3.5.2   Scanning CIR Transparency Film

To evaluate and compare the two types of imagery supplied for the study sites, the CIR transparencies were scanned into digital format. Three kinds of scanners were used, an inexpensive flatbed scanner, a medium-format unit used by the Forest Service, and a high resolution scanner provided by Colorado State University. Recent developments in

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optical scanners have made digitizing 'hard-copy' images easy, and if exceptional detail is not needed, the cost is low. Conventional photographs and transparencies can be quickly converted to digital form with a scanner, and saved in a variety of computer file formats. Operational use of scanned CIR transparencies is now increasing in demand. (Jim Ellenwood, personal communication, 2001) Supplied CIR transparencies were scanned with three scanners, including a very high resolution device, and examined for information content. Two areas of this technology are to be carefully considered. The first is the choice of digital file format, and the second is scanning resolution.

File Format

The computer file format chosen to store images is not a trivial issue. Some formats were created for the efficient compaction of visual elements, and not for the archive and storage of original image data values.

A term used to describe a file format that does not change the data is 'lossless'. This means that the original data can be saved to this format, and when read, can provide an exact duplicate of the original. The .TIFF format is common and lossless, but has no inherent compression. Optional LZW compression may be safely applied to .TIFF files to reduce the size of the file, but this particular compression is proprietary, and requires a specific license within the host software. This is a fine format for imagery that will be classified. This is limited to about 4:1 reduction in file size.

Other file formats that simplify the image data to reduce the file size are called 'lossy'. Options may include the .PNG (ping) and .SID (MrSid) formats, suitable for some purposes. 'Lossy' formats used in displaying images, perhaps for display on the Internet, are to be used with care, such as .GIF (pronounced 'jif') and .JPG (J'peg). All of these formats trade file size for fidelity to the original. In saving data to these formats, an algorithm is used to compress the information. This is fine for artistically oriented pictures, but may destroy subtle information available from an image data file. Some compression algorithms map the frequency pattern and discard high frequency elements. Others reduce file size by using a sort of mathematical shorthand to indicate that many pixels of a given value occur together, or that a range of values can be saved as one value. These use 'color maps' of human eyesight to create as much imperceptible duplication as possible. For this reason, the amount of compression possible is based on the uniformity of the data and characteristics of the algorithm. Paola and Schowengerdt (1995) found that low levels of .JPG compression (10:1) did not appreciably affect classifications made of the compressed data. If the classification is to be smoothed, and pixel level detail is not needed, the common .JPG format may be suitable. (Johnson, Greenfield, 1999)

Once digital image processing has been accomplished, versions of the data files may be prepared for the internet, reports, printing paper copies, or any other use. Format is less critical for these needs and may be chosen for convenience. (Milburn, 2000; Dougherty, 1999) Digital image data saved as .TIFF computer files make good slides and overheads for presentation. (Knapp, Disperati, Sheng, 1998)

Scanning Resolution

Transparency film has been described, in digital terms, as having an information content of 10.16 to 6.35 μm (2,500 to 4,000 pixels per inch (ppi)). Small format scanners for use with 35 mm slide film may acquire 9.41 μm, or 2,700 spots per inch (spi), or more. Expensive large format drum scanners are available with 3,000 dpi capability, and were used in this study. This unit produced a file that demonstrates what can be done with a high-end scanner, but would not normally be cost effective for production use.

All scanners sample this very dense information surface, and create an image using some type of algorithm, which may not be documented. Since all scanners represent continuous data with finite sampling, there is a loss of information in the scanning process. Scanners have a variety of possible resolution settings, but most are mathematical interpolations from the linear array 'optical resolution'. A possible second 'true' resolution, available on some models, is a magnification of the first, through a lens system, with corresponding loss in scan area. To minimize effects of subsampling, the optical resolution of the scanner should be used for precise imaging. This does not produce an unaltered data set, however. Interpolation is inherent to the scanning process, starting with the conversion from analog to digital signal, and in later processes. The output from the scanner is a computer file. (Milburn, 2000; Dougherty, 1999; Ritchie, Meade, 1995)

Scanner Hardware Description

A high quality scanner available locally is one used operationally by the FHTET group of the Forest Service. This is used operationally to digitally capture aerial photography. The Umax® Data Systems, Inc. Mirage II scanner is rated at 700 spots per inch optical resolution. A calibrated light source is used to illuminate the scanned media, is reflected off, then directed through a lens, split into red, green and blue wavelengths by a prism, and sensed individually by a moving tri-linear CCD (Personal communication, Umax Technical Support). These values are converted from analog to digital signal, quantized, and become the digital numbers (DN) available in an output file.

For research purposes only, a Scanview brand Scanmate 3000 drum scanner was used to capture one 9 x 9 transparency. This was accomplished by CSU Photo Services. Both of these were compared qualitatively to an inexpensive PC flatbed scanner.

Scanning Software Processing

The scanning process for the Umax flatbed scanner requires shifting the 'native' 36-bit preview histogram to select an optimum 24-bit output. This may be done automatically by scanner defaults, or by the operator manually, and can be done individually for each of three 12 bit RGB bands. If no shift is specified, then about a third of the 24-bit radiometric resolution remains unused. There is no usable 'raw' data set, as the data values are by necessity assigned to 'bins' to suit the analyst when converting to normal non-proprietary formats. Adobe PhotoShop, using Kodak 'plugins', are one option for these initial processing steps and were used for this study. (Umax Mirage II Color Scanner Operation Manual, 1999). Histograms can be viewed to determine if the dynamic range has been captured correctly.

4 RESULTS

4.1 Field Observations

Stumps and remnant fence lines dissect lower Sage Hen. Juniper was cut for fence posts. Many vehicle tracks through the vegetation have partially revegetated. Some tracks visible from the air, are now not perceivable from the ground. Erosion from recent ATV use is evident, and common. Crushed vegetation, overturned rocks, and ruts are some of the current damage from off-road activity which is easily found. Many sediment traps and road closures have been violated, or damaged. The mud and sandy area around the reservoir, below the high water line, is tracked with vehicle and foot traffic. Other signs of human use exist. The forest is littered with trash, mostly glass and aluminum beer bottles. Rusty cans, old auto parts and small rubbish dumps are found over the landscape. There are locked gates and an administrative wildlife closure about the area in winter, discouraging ATV and four-wheel drive recreation activity within. Blackened rings of rocks, record campfire use in the forest. This area was grazed by sheep decades ago. The area has an ancient record of human occupation (Breternitz, 1988).

4.1.1 Vegetation

In this area, *Pinus edulis Englemani* (piñon pine, pinyon pine, two-needle pine) is in approximately the middle of its elevation range, and occurs with *juniperus scopulorum* (Rocky Mountain Juniper) and *Juniperus osteosperma* (Utah Juniper). The mean height of piñon at this site is about 3.7 m (12.1 feet) with a standard deviation of 1.7 m (Kearns, 2001). Below this altitude range is purplish *juniperus monosperma* (One-seed Juniper) and *Juniperus deppeana* (Alligator Juniper). Above the piñon is *Pinus ponderosae* (ponderosa pine) (Aldon, Shaw, 1993). Only two have been noticed in this study area, but they occur on this side rarely. There are ponderosa forests on the east side of the reservoir. *Artemesia tridentata* (Big Sage), *Crysothamnus nauseosus* (Rubber or Common Rabbitbrush), *Cercocarpus montanus* (Mountain Mahogany), and *Amelanchier Medic A. pumila Nutt. ex T. & G.* (Serviceberry) are common. *Ribes leptanthum* (Western Gooseberry) and *Ribes montigenum* (Alpine Prickly Currant) intertwine with other vegetation. *Quercus gambelli* (Gambel oak) occurs as single shrubs to large patches. *Escobaria vivipara* (Ball Cactus) and *Opuntia fragilis* (Brittle Prickly Pear Cactus) are occasionally found on sunny exposures. Coarse grasses and cryptogam hold the loamy soil together. Piñon-juniper is most common up to 2,225 m (7,300 feet) and oak is predominant to 2,347 m (7,700 feet). (Petersen, 1985) Exposed rock may develop lichen.

A total of 1,631 crown observations were made. Table 1 is a summary of the observations on the ten images. There were 1,071 piñon, 415 juniper, and 145 piñon in various stages of fading and decline. *Any visual indication that a tree was in distress was placed in the latter category. Conditions from a slight yellowing of the branch tips to a dry blow-over have been included in this tally.

These figures are not to be taken as a proportional sample, however. Juniper are probably over represented in the count, since they were usually identified for forest navigation, and all fading piñon were identified and counted, since they were the target of the field investigation. The counts underestimate trees which have lost all of their needles since the time of the imagery. These are difficult to identify, since they frequently blend in with previous mortality centers, and the dead crown is not available to positively identify the tree. Isolated mortality is easier to identify, since surrounding trees can be used to provide navigation clues. Real time GPS would be helpful for this task.

Crowns Field Checked

Image	Piñon	Juniper	Piñon* Faders	Image Totals
20012	65	4	2	71
20041	32	4	0	36
20042	111	21	8	140
20055	56	19	0	75
20059	277	104	33	414
20073	157	145	9	311
20074	150	54	45	249
20078	19	22	4	45
20091	101	21	2	124
20092	103	21	42	166
Totals	**1071**	**415**	**145**	**1631**

Table 1 Crowns field checked

4.1.2 Cryptogam

One of the significant soil cover elements is a crust of mixed lichens, mosses, and algae. This is most apparent in open areas. A dark shadow effect is produced by some types, and under moist soil surface conditions, is very apparent to the eye, especially during the winter trips with recent rain and snowfall. (See Figure 5) The fourth trip to the study site, made in late September, revealed deer trampling of the cryptogam, and late summer drying that made it much more difficult to detect. When dry, the small mounds of castleated soil appeared to be reduced, and in some areas, grass had grown up through the small mounds, and were senescing. Geneva Chong notes in an unpublished report, "… transects also show that up to 30% of the surface can be covered by microphytic (or cryptogamic crusts) … (Bandelier, unpublished data 1992)" (Chong, 1992)

Figure 5 Cryptogamic Crust

Although outside the scope of this study, a rough guess of cryptogam cover in this area might be 20%. This figure overlaps with grass cover, as the two coexist, and may be more obvious to the eye at different seasons, and under different moisture conditions. Shadow, and trampling by deer may further obscure, or confuse the detection of these castelated mounds.

Disturbance and mortality is often associated with visible changes in the proportion of the cryptogamic constituents. Five to nineteen percent crust and lichen cover was found in New Mexico at a slightly higher elevation. This was found to be variable across the landscape and is a function of vegetative cover, moisture, pebble distribution, needle fall and woody debris. Black crust may be composed of cyanobacteria and other unicellular algae. A moss crust, and foliose, crustose, fruticose lichens contribute to the soil cover. "A dead, decaying tree on transects 8-12 m long apparently reduced the cryptogamic cover. This could be due to allelopathic effect from the decaying wood. An alternative explanation for the observation could be that, in general, cryptogams are slow growing and slow to recolonize an area that had suffered the inhibitory effect of a canopy and debris and the disturbance (both within the soil and at the surface) after tree fall." (Ladyman, 1993)

The lack of cryptogamic development in an open spot may be used to help identify areas that have had recent vegetative cover, are experiencing erosion, are very rocky, or that are shaded through much of the day.

A related condition is the black fungus that forms on piñon bark. This is obvious on piñon stems, and persists for many years on the dead bark material and pieces that fall to the ground. The large, dark area under the crown of previous piñon cover appears to be caused by this effect. However, crowns may break off and be blown to another spot.

4.1.3 Soil

Generalized soil maps are available for the area. However, the most current county updates to soil maps in the area fall just short of the study area, as seen in SSURGO data provided by John Norman, Colorado State University.

Fine scale topographic detail controls the exposure of loess or underlying alluvial deposits. Alluvium came from extremely varied sources, resulting from streams feeding the ancient Dolores River. Yellow and red soils are found today in the study area. Outside the scope of this study, these colorings may influence the background reflectance in sparsely vegetated areas. This may cause additional variation in spectral reflectance when examining shrub and grassland areas in the future. Sloping soil surfaces are often paved with gravel and cobbles. When exposed to sun for long periods, these lithic materials develop many kinds of lichen, which often appear as a darker coating in DCIR imagery, similar to cryptogamic development.

Exposed rock is common in many places, and is usually a light yellow in color. This is strongly reflective in all color infrared wavelengths, and appears white in the DCIR images. It is clearly different than the blue soil tones. Cracks in concrete show up well, but this may be due to vegetation in the cracks. Pavement patches and condition are clear. Wet spots in the gravel roads are clear.

Fence lines, game trails, and vehicular traffic work together to aggregate surface runoff, and produce swift erosion in heavy rain events. Vehicular travel in muddy conditions

severely erodes this soft soil. There is significant erosion on roads and trails, and this is clear in the images.

Fire

There is no evidence of significant fire in the studied area. Lightning scarred trees are common, but little more than a particular tree was affected. Piñon is a fire sensitive species, which is easily killed by wildfire. The existence of many ages of trees, and 350 year old individuals, indicates limited fire activity during the lifetime of these trees. (Personal communication with Bill Romme, April 2, 2001)

4.1.4 GPS - Global Positioning System Data Results

Using the first field trip's GCPs and plot center verification points, the background DOQQ was found to be accurate within 7 meters. It was used as a background GIS coverage in the computer lab. This black and white image was overlayed with other GIS features, such as previously identified mortality centers and plot center points, roads and public land use system boundaries. The GIS images from this combination helped locate fencelines and was sufficient as a rough field navigation aid.

This was not accurate enough to identify tree crowns accurately in the field, but helps get close enough to use larger scale imagery such as the DCIR images. Distortion in the DCIR images proved to be a problem. Fencelines took an 'S'-shaped curve in the unrectified images taken from 1,000 and 1,500 feet, but were less noticeable in images taken from about 2,000 feet. Accurately locating individual trees from any of the images was difficult in places. GPS locations of individual trees and landmarks were used for navigation during the first two trips.

DCIR maps were successfully rectified for field use. At this scale, six points per image is enough for field use, if precise mosaicking is not needed. Acquiring GCP points in overlapping portions of imagery was the most effective use of time. (An alternative method would use DOQQ locations only, if precise fieldwork is not planned.) Rectified maps and experience on the site made later trips much more productive, and reduced errors.

GPS equipment worked well. The open canopy did not block the satellite signal in most cases. Low lying areas are more difficult to obtain signal in. Snow and rain had no effect on the GPS equipment during the first three trips, but batteries must be kept warm for full use. Water bottles were heated and packed in extra cold weather clothing layers to keep them from freezing. A 4 amp-hour gel battery packed this way was the longest lasting option tried, and provided power for ten hours inside a backpack. These are half the price of 2.2 ah video camera batteries usually used, but twice the weight. The small E-Trex unit was kept in a warm shirt pocket. An external antenna fastened to one's hat or pack is helpful, as a larger handheld unit with integral antenna is difficult to hold in position for extended periods.

Tighter GPS set-up and correction parameters had little affect on accuracy, as five of the Kearns GPS plot centers matched the higher quality fixes acquired in this study to within 2.5 meters. PDOP values of under 8 may be accurate enough for determining most locations, and are faster to acquire at times. Waiting for PDOPs of 6 or less takes more time unless satellite constellations are excellent.

Transects were identified by finding the plot center stakes and following handheld compass azimuths. Dead trees had bark stripped off, and were obvious. Transect ends were marked with tags, but some are missing or hidden. Exact transect positioning was difficult to duplicate, given the dense and tangled nature of the vegetation. Two transects were attempted, but the routing of the tape through, and around shrubs and trees was labored. Figure 6 is a shot down one transect, illustrating the situation. Also, the DCIR image data shows crown masses from above, while Kearns described stems, which were usually indistinguishable from above. Werth and Work (1990) make similar observations, noting that identifying the exact path of a ground transect on canopy photography is "virtually impossible", and that small deviations from the true transect resulted in large statistical errors. The attempt to use the exact same data as in the Kearns study was abandoned. Tree crown masses which were seen on the DCIR images were examined instead.

Figure 6 Transects in dense piñon and oak proved to be too difficult to follow exactly.

4.2   Remote Sensor Data Results

4.2.1   CIR Transparency Inspection

Several transparencies of the study area were available for inspection. The 1:6,000 scale, 9 x 9 inch, Kodak 2443 CIR transparency film was inspected with a 40x microscope and various loupes from 4 to10x. Light sources from above and below were used. One of the transparencies was scanned with a very high quality 3,000 dpi optical scanner.

At high microscope magnifications, the remaining silver-halide crystals are barely visible, and look a bit like clouds, with three-dimensional qualities. Scratches on both sides of the film are very noticeable, and plentiful. Edges between vegetation and soil are clear, and the transition zone between them is distinct. Fine detail may be best viewed at about 20x magnification. Microfiche viewers are sometimes used for convenience. Vignetting and parallax is present in the transparencies, and sometimes only the middle

of each frame can be used. This is less of a problem with short tree species found in arid areas.

Much preferred to manual methods was examination of the scanned version of the transparency on a computer monitor. Ease of use, and less eye fatigue are benefits, however, the ability to subset and copy areas of interest are the primary advantages. The digitized transparency had noticeably less detail than the original, as observed by the detection of downed tree trunks and branches, in the scans obtained from the inexpensive PC scanner. The high quality, large format scanner used by the Forest Service worked well at resolutions over about 500 dpi. However, interpolation between pixels causes a fuzzy appearance, so 600 dpi or higher is recommended. It did not appear that the 700 dpi optical resolution of the scanner could be used without interpolation. The 3,000 dpi drum scanner produces very clear images, and in this 1:6,000 scale transparency, branch details are clear. The cost of $30.00 for each scan may not be operationally feasible. This scan is of the entire 9x9 inch transparency; however, so for applications where the images are to be shared it may become cost effective. Scratches were not visible in the scans.

It would take two or three exposure levels to make a record of all landscape elements in CIR transparencies. Jim Ellenwood indicated in personal conversation that in choosing an optimum exposure for tree crowns, soil tones are overexposed, or 'washed out'. This is noticeable in this particular imagery. Soil areas in this photography appear as a fairly uniform light blue color, and rock is indistinguishable from dry soil. Areas of dried grass, bare soil and cryptogamic areas all appear similar. However, moist soil is differentiated from dry soil easily. Piñon crowns are a darker red in comparison to pinkish juniper. Red crowned fading trees show a clearly greenish tone on the film. Small woody debris is not readily identified. Fallen pine needles and small woody debris do not appear different from soil. Piñon mortality centers are represented by gray woody debris against a light blue background. Gray against blue is a low contrast difference.

4.2.2 DCIR Observations

The current footprint of small format CCD imaging devices limits the area of coverage. This requires a tradeoff between detail and the number of images needed. However, the size of the sensing arrays is increasing. At this time, the devices are suitable for creating high spectral and spatial detail images. With additional effort, mosaicking may be performed. This usually requires some degree of spatial and spectral processing so that the individual frames will join smoothly. Vendors provide these services as part of normal processing, at the request of the customer. (Personal communication, Positive Systems, Inc., January 23, 2002)

Appearance of Vegetation in Digital Color Infrared Images

Images were supplied as LZW compressed Tagged Image File Format (.tiff) files, with histogram stretching applied. There was no metadata supplied. Preliminary review was done in the Advanced Technology Laboratory at Colorado State University. Several image programs were used to display the data on-screen. The shareware program

ACDSee Classic was helpful for general image review. Adobe *Photoshop* and ERDAS *Imagine* were used for enhancement and analysis.

A false color composite of the three data bands was preferred for review. This digitally simulates traditional color infrared images. Species determination is easy in the field with properly prepared paper images produced on an inkjet printer. (See Figure 7) The most obvious feature on the imagery may be (A) the large dark patches of piñon mortality. A pixel mixture of graying needle fall, a black fungus that grows on piñon bark, and the lack of vegetation under the previous crown extent, creates a very dark circle. These may overlap, have regeneration or unaffected vegetation within, or be fractured with fallen trees or branches, but in any case, they are dramatic.

Figure 7 DCIR features

The largest discrete features are (B) individual juniper and (C) piñon crowns. Juniper looks bluish-pink, with much variation due to an open crown, and piñon is a compact dark rusty-brown. Gambel's oak (D) has a very distinct bright reddish-orange color and dappled texture. Shadowing under the plant is dense, and is the cause of the notable texture. The leaf masses tend to clump and shade the underside, which blocks sensing of material under the shrub. Oak in this area may grow to 18 feet and may cast a shadow for some distance, but shadow was minimal in imagery for this study. Fading crowns (E) and red needle fall are seen as shades of green. They are rare in 1999 imagery.

Shrub discrimination in the forest is complicated by the mixing and intertwining of several plants into patches. In addition, many species have a dead or bare wood integrated in the living mass, breaking up the continuity. Fendler brush and current have some bright red pixels, and a majority of dark muddy-purple pixels in a two part color combination. (See Figure 8) In the open areas, sagebrush (F) appears as a dark purple or olive, and may have brighter soil around it. Rabbitbrush (G), growing as distinct clumps in the open grassy meadows, are seen as small dots of bright red, with little debris accumulating about the base. Other shrubs may be picked out by seasonal characteristics. Western gooseberry is the first to develop leaves in the spring, rabbitbrush produces yellow flowers, and mountain mahogany is purple in winter. These conditions were not tested in the single-flight data available for this study.
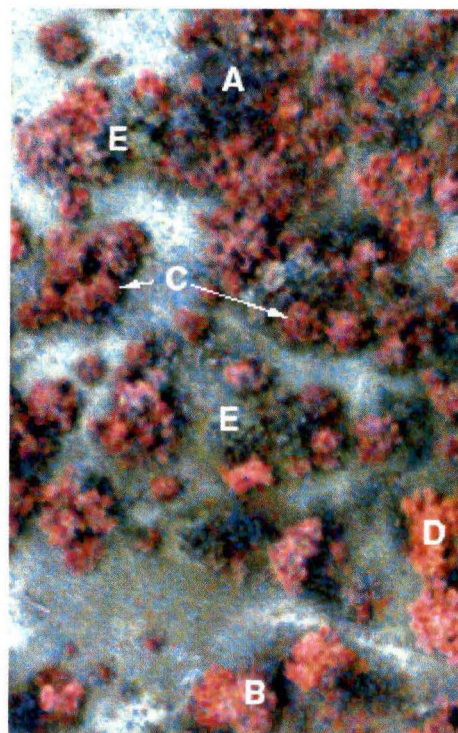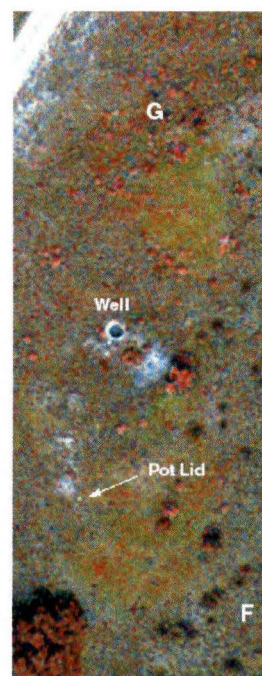

Figure 8 Shrubs in open areas

Surface conditions such as rock, bare soil, leaf accumulation, dry grass, lush grass, and perhaps cryptogam are evident. Rock outcrops, recently uncovered stone, and even small stones of 6" can be resolved. Bare soil is light blue, and rock is nearly white. In this way, stream courses, erosion, and areas with severe trampling are found. Few areas were found with bare soil not created by grazers or vehicle damage, but slopes with gravel and stone 'pavement' were captured that appear to be caused by natural processes.

Small woody debris such as oak and other shrub leaves can be seen in the imagery where the accumulation extends out from under the plants. (Refer to Figure 9) In this area, the North side of the shrubs may collect the most noticeable piles. Solar decomposition or wind direction may play a part in the lack of debris on the South sides. Some images showed accumulation on the west side. Dry Gambel's oak leaves have a distinct signature when not mixed with other material.

This imagery has little shadow present due to overcast conditions. Small woody debris was first thought to be shadows, but compact crowns were observed as having little or no shadow throw. This signature was investigated on the ground, and found to be a reliable sign of some kind of small woody debris, usually shrub leaves lost at senescence, but can be heavy needle accumulation.

Figure 9
Small woody debris

Large woody debris is visible in the imagery to the eye, and has a gray signature. In many cases, this can be seen near bare soil or rock, providing the opportunity to discern it from similar colors. Individual branches are resolved when dry, bark free, and over about 8" in diameter. The stump mass may be clearly seen when above ground. This is common, as many large trees blow over. Dead piñon are frequently broken at about 4-7 feet off the ground, with the upper portion traveling some distance before coming to rest. Figure 10 shows a mortality center, with a top missing from one four foot stump. This may break up the snag, and distribute branches. The rest is broken up quickly, and is in small enough pieces to be detectable as general woody debris, without the exact source clear. The gray debris tends to look bluish in the imagery when viewed against the dark mortality background. It should be noted that a vertical stump or snag, when viewed from above, is seen as just a few pixels, and may not be discernable.

Figure 10 Large woody debris, broken trees, and black fungus on piñon bark

New wildlife tracks often follow man-made linear features such as fence lines and off-road vehicle tracks, or old jeep roads. This tends to create further erosion, disturb the vegetation, and make these features continue to stand out on the imagery. There are, however, features which are entirely obscured on the ground, which show up clearly on the aerial images.

Indications of topographical relief is nearly absent from this particular imagery. There is no obvious shadowing to determine high and low ground. Topographic shading might be visible from a higher vantage point with sunny conditions, but not with the small areal extent and overcast conditions found in these images. A rocky feature that appeared to be a ridge-former turned out to be a deep stream course, with washed stone bottom, and plate-like stones jutting from the lower portion of the bed. Other imagery donated from researchers shows that in sunny conditions, topographic relief is clear when imaged from about 4,000 feet AGL.

Man-made objects were found in the imagery and on the ground. Rusty auto parts and an 8" aluminum pressure cooker top were discovered. The deeply rusted steel and iron signature is red, and the bright aluminum surface was light green. An odd looking object thought to be an unusual shrub was found to be a large roll of barbed wire. A trash dump consisting mostly of rusted #10 cans, and some fuel containers did not stand out in the imagery, but when located with GPS, did indeed have a red signature, but pixels were scattered. Grass between the metal may have helped obscure the dump.

Tracks made by off-road vehicles appear to revegetate if on very low slope surfaces, but the alteration to vegetation is visible long after. Deer and elk routes are much less prominent than man-made tracks, in that they do not usually lie in straight lines, and often go under tree crowns, and in very close proximity to available cover. Figure 11 shows an example of an illegal, and heavily impacted, recreational vehicle camping area. Damage to the grassy areas is not visible from the ground.
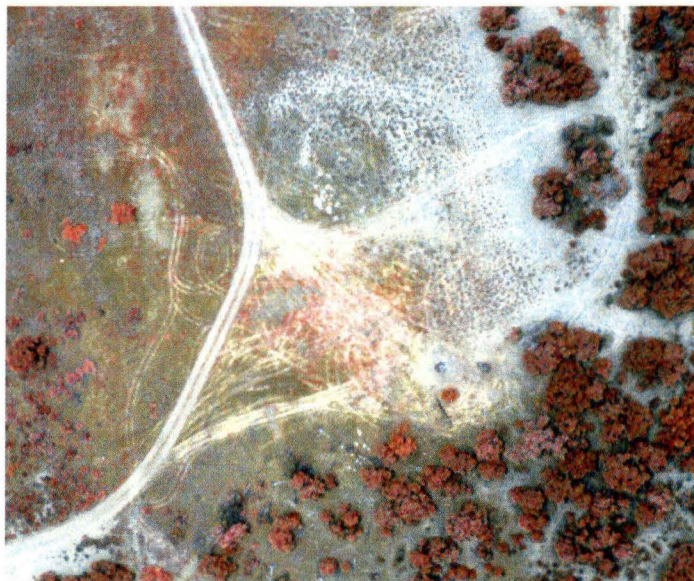

Figure 11 Damage from off road vehicles

4.2.3   Comparison of CIR and DCIR

Qualitative analysis of this particular set of transparencies indicates that much less spectral information is captured in the CIR photographs, compared to DCIR images, but the spatial resolution is currently better. If the two images had been obtained at the same scale, the spatial resolution of CIR transparencies would be far superior. Scanning at high resolution may currently be the best way to get wide area coverage, and enjoy the benefits of digital data.

At this time CIR and DCIR images taken at the same scale have not been identified for a piñon-juniper landscape. Comparison between the two sets of imagery that were supplied for this project can only be approximate and qualitative, due to the very different scale of the original images. In no way is the following a 'fair' comparison, but some basic differences are apparent. These images were acquired at different times, different heights above ground level, and with different lens and filter combinations. In Figure 12 below, a CIR photo is represented on the left (A), and a DCIR image is on the right (B). The CIR photo was taken from approximately 4,500 feet above ground level at a scale of about 1:6,000, scanned from a 9x9 inch transparency at 3,000 dpi, and cropped to the area of an entire DCIR scene. The DCIR image was taken from approximately 1,500 feet above ground level, at a scale of about 1:10,900. Neither image has been formally rectified as displayed here, but the CIR image was rotated and sized to match the DCIR image. The printer used to reproduce these images has a 600 dpi specification.

There is much more spectral detail in the DCIR image. Notice the difference in meadow tones, which have live and dead grass, as well as cryptogamic development in the lower left meadow. In general, the CIR image does not provide detail in the blue soil areas. Fading crowns are only gray in the CIR image, but have a variety of greenish hues in the DCIR image. Mortality centers are seen in the CIR as thready shadows below grey branches, but are obvious large black patches in the DCIR. Crown coloring is more varied in the DCIR image, and with little training, an analyst can differentiate tree species. Animal tracks, shrub cover, grass cover and other features are much clearer in the DCIR image. The scale of these images as printed here, are approximately 1:1,840.
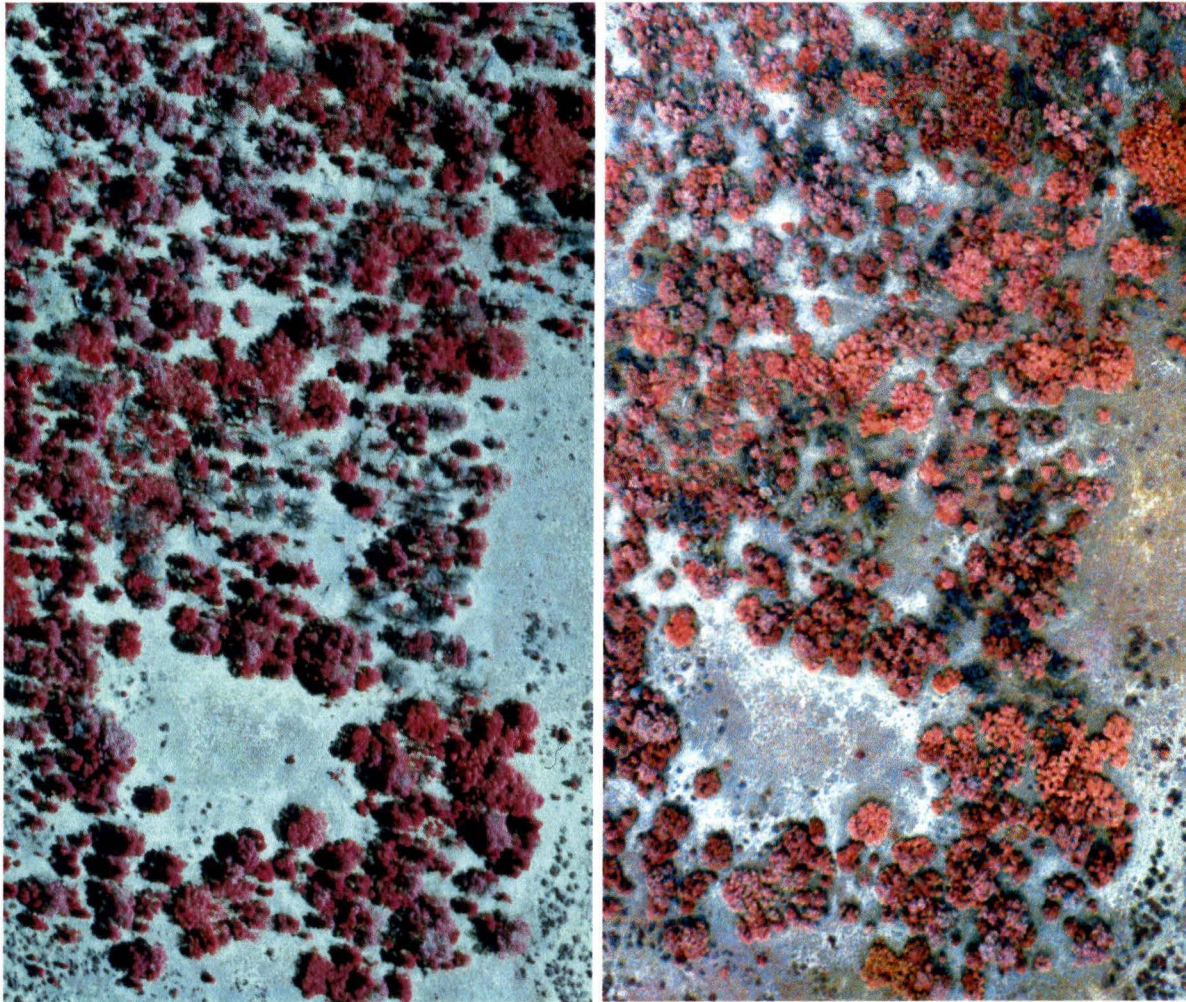
Figure 12   **A**

Enlargement of a small portion of a 9 x 9 inch CIR transparency originally photographed at 1:6000 scale. The image was taken from about 1,310 m (4,300 feet) above ground level in August. This is taken from a 3,000 spot per inch scan. The scale of these images are approximately 1:1,840.

B

Entire Kodak DCS420 DCIR scene. This image was taken from about 305 m (1,000 feet) above ground level, at a scale of 1:11,000 in June. Both images are unrectified, have had histogram stretching applied, and show a similar area on the ground.

The most fundamental difference in the two images may be that the information is primarily textural in the CIR image, while the information is mostly spectral in the DCIR image. This is more apparent in Figure 13. These are two enlargements of mortality from the comparison above. Notice that individual branches, and the shadows cast by them, are clear in the CIR photography (A), where only a general impression is visible in the DCIR image on the right (B). Dark fungus on fallen bark pieces make the patches more apparent, but there is little shadow in the DCIR. The eye may be fooled into seeing more texture by the diversity of color in DCIR, but it is not truly there.
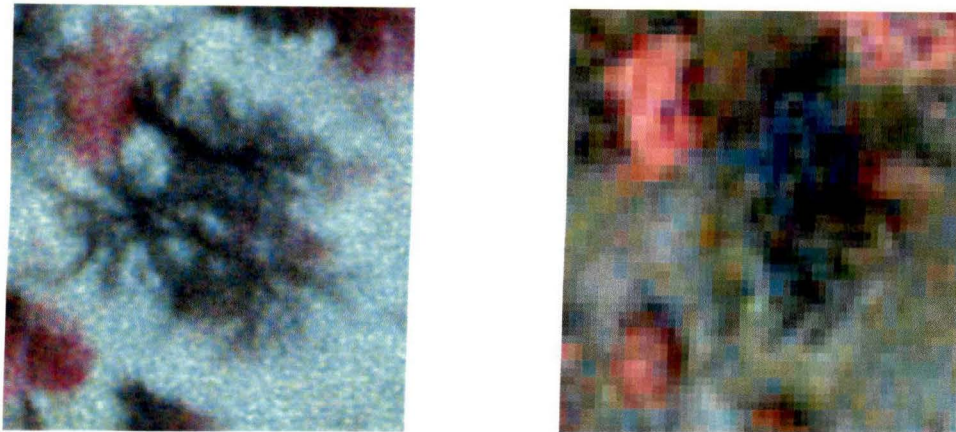

Figure 13   A   B

Even at greatly different scales, CIR has much better spatial resolution than DCIR

4.3   DCIR Computer Assisted Analysis Techniques

Inexpensive image display programs are sufficient for a quick review of the imagery. However, many features exist in advanced image processing programs that help an analyst to bring out additional information. Analysis with ERDAS *Imagine* is particularly helpful. The images were studied at a variety of zoom levels, adjusted for brightness and contrast when needed, cropped and saved to several presentation formats. Various band display combinations were tested, and the standard color infrared band arrangement was preferred. Infrared is shown as a red display color, red is shown as green, and blue is shown as blue. (Beginners may prefer another arrangement that is more intuitive, such as showing the infrared band as green.)

Classification of the DCIR images was attempted with both 'supervised' and 'unsupervised' methods. The fine resolution of this imagery created a problem which interferes with supervised techniques, and was first noticed in mortality patches. Shrubs, grass, bare soil, and small trees may be found within mortality patches, and provide a confusing variety of spectral signatures. In the images studied, crowns are also composed of a mixture of materials and signatures. (See Figure 14) Crown and shrub signatures are too highly textured, and spectrally diverse. Training polygons provided spectral signatures that were too wide. For this reason, results of a classification using the supervised method were rejected. An exception may have been soil and grass areas,

where homogeneous training polygons are available, but should be severely trimmed of outliers.

The unsupervised method proved to be more suitable for these 6" resolution images. Pixels exhibiting obvious patterns were identified as fallen trees, logs, or rock outcrops. With field verification and by process of elimination, each class was identified. Those spectral cluster classes that contain multiple covertypes were deleted, combined, or further divided in a 'cluster busting' strategy. By way of elimination, other features such as woody debris, bare soil and shrubs were identified.

Many tree crowns and shrubs have dead or bare wood showing in the living crown mass, breaking up the continuity and lending a bluish-gray 'dry-woody' signature to the pixel set. In Figure 14, a juniper and piñon crown are seen next to one another. The pinkish color of the juniper is composed of a few unique juniper pixels, many dry wood pixels, and many pixels which are found in any conifer in the image.
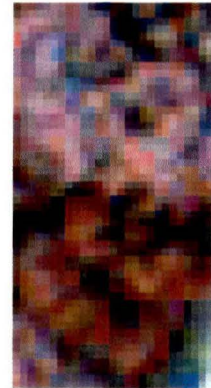
Viewing images at the pixel level suggests that much of the pink juniper color is a human perceptual amalgation, as the pixels are actually red and gray. In a similar way, the piñon crown is composed of many conifer pixels, some dark shade pixels, and some pixels that are usually found only in piñon. These combine to give a dark red impression. There are several signatures that are mixed in with both crown types. Conifer, 'dry-woody', shadow, soil, and shrub signatures are associated with most crowns.
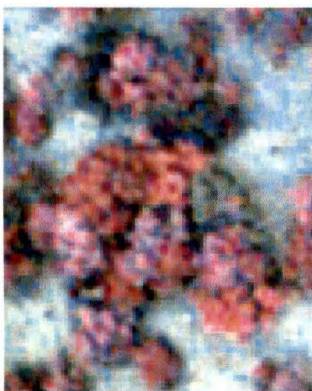
Figure 14
Juniper and piñon

Figure 15
Black and green piñon mortality

Piñon mortality appears as a bluish black patch on DCIR imagery, and in a similar way, pixel analysis suggests that much of this is a combination of some bluish-gray 'dry-woody' pixels, and the dark mortality signature. (See Figure 15)

In unsupervised classification, juniper-only spectral signatures were found with an initial clustering of 25 classes. A distinct juniper signature is available for only a few pixels in each crown, but the pixels are diagnostic. The lack of blue wavelength sensing in this system may be a disadvantage in this case, as juniper has a bluish cast when viewed with the human eye, and this might be used to advantage in future studies.

Piñon crown pixels have more confusion with other classes. Most of the tree crown masses are piñon, so identifying the juniper crowns first is an important step in eliminating confusion between species. Spectral overlap is found between most classes, but there is often a unique spectral signature that can be identified with 'cluster busting' techniques. (See the spectral grouping section for a description of this image processing technique.)

It would appear that smoothing or majority filters may be useful at an early stage in spectral analysis. When the original image data is smoothed, pixels are created with spectral characteristics falling between existing ones. This has two effects. The first is that the new pixels may not represent real reflection characteristics, but can be useful for analysis. Second, groups of pixels may now be isolated that more closely match the way a human perceives the data. Computers treat each pixel as a separate data element, while the eye tends to smooth the data. This is illustrated by the previous example of juniper appearing bluish-pink, when there are few actual bluish-pink pixels in an image.

With this in mind, a smoothed data set was created using a 7 x 7 'low pass' filter. This was found to be effective in preserving important details. The only drawback was in the loss of woody debris signatures about the bases of shrub patches, and fading crowns. This set was classified, and found to be a faster way of analyzing the image, as extraneous detail had been reduced. It should be remembered that this will, by necessity, introduce artificially created intermediate data values into the DN set, not truly sensed by the imaging device. This affect was trivial in this high spatial resolution image, but could be very noticeable in imagery taken from higher altitudes since the pixel size would be larger. Presentation image products are seldom displayed at full resolution, and usually have smoothing applied to create a more pleasing image, so it may not be an issue except in the analysis stage.

It would appear that a smoothing or majority filter may be of utility in reducing overly detailed information in the color infrared images. However, a differential majority filter is more useful, since some signatures are very specific, and others occur in many types of crowns, and require context information to determine their class type. Perhaps the best solution may be proximity analysis, using GIS raster (grid) analysis procedures. This is helpful for clustering pixels which compose an object. This can be programmed to identify contiguous pixels in tree crowns, large woody debris, bare soil, roads and mortality. Additional steps may be added to buffer diagnostic pixels, and recode non-determinant pixels to nearby diagnostic values.

5   SUMMARY AND CONCLUSIONS

5.1   Primary Results

Original project objectives were summarized as follows: (1) Determine the capability of Digital Color Infrared Photography (DCIR) to detect *Pinus edulis* (piñon pine) stress from *Ips* bark beetles or black stain root disease, (2) Determine the effectiveness of DCIR, in comparison to conventional color infrared photography (CIR), for detection of infested trees, (3) Define the earliest stage of stress that can be detected using DCIR, (4) Determine the potential effectiveness for using computer-aided analysis techniques to identify and map infested trees, and (5) Document appropriate automated computer processing techniques for mapping the location of mortality and stress.

Each of these objectives have been met, and a summary of the results are provided for each one.

❑   **(1) Determine the capability of Digital Color Infrared Photography (DCIR) to detect piñon pine stress from *Ips* bark beetles or black stain root disease.**

Black stain root disease and Ips bark beetles affect moisture transportation in piñon. This results in changes to the infrared reflectance of the needle cell structure, and a decrease in chlorophyll reflectance. Pre-visual spectral changes have not been found to be evident in this particular set of conventional Color Infrared photographic transparencies (CIR), or Digital Color Infrared (DCIR) imagery.

Several stress detection indices were evaluated. NDVI, IR-red, IR-green, red-green, principle component analysis, and ratio analysis did not reveal a clear diagnostic spectral signature for pre-visual stress.

Difficulty in finding a stress signature may have been due to any combination of the following four issues: date of imagery, resolution of imagery, stem to crown health descriptive data, and lag time in identifying stressed trees. (1) June may have not been the best time to collect stress data imagery. Elevated air temperatures and decreased soil moisture may be a greater stressor to deep rooted piñon at another time of year, such as July or August. (2) The resolution of this imagery may have been too fine to capture general crown changes that may be apparent over several meters. Perhaps imagery collected at the one or two meter spatial resolution would reveal morphologic changes such as crown thinning. (3) Biologic data for this study was taken for stems, but not related to the crown masses on imagery. Individual branch clusters are visible in the DCIR crown clusters, but it is not clear which stem information corresponds to which crown mass. This is both a spatial accuracy issue, and a data collection issue. The research team must have imagery in hand while collecting the stem health information. (4) There was a three year delay in identifying crown health on the DCIR images. In this time, mortality took place, and the first trees to die were difficult to find in the field. The

crowns break up quickly, and are hard to identify individually. Also, it was not possible to describe the rate at which stress, chlorosis, needle fall and breakup of the crown occurred.

☐ **(2) Determine the effectiveness of DCIR, in comparison to conventional color infrared photography (CIR), for detection of infested trees.**

Traditional Color Infrared transparencies (CIR) record superior crown structure details, and excellent spatial texture, but provides little spectral detail. Thin and dead crowns are detectable with a loupe, but are easy to miss if mixed in with other vegetation. Fading yellow and red crowns are visible, but not very obvious. Digital Color Infrared (DCIR) imagery provides higher spectral resolution than CIR. At this time, DCIR has lower spatial resolution compared to film, due to small Charge Coupled Device (CCD) size, but vendors are increasing the size of the chips at a rapid pace. When analyzed with image processing programs, DCIR has the ability to identify many more landscape features, despite lower resolution.

Review of DCIR images by eye on a computer monitor, or on prints, can differentiate piñon and juniper, piñon mortality, fading piñon crowns, as well as grass, bare soil, rock, small and large woody debris. These take no skilled image enhancement techniques to be visible.

Fading piñon crowns can be seen easily in DCIR when they turn yellow. There were too few crowns in an early stage of fading to identify the precise point when this is clear on the imagery. Early signs of piñon stress were not identified on the CIR photos at all.

☐ **(3) Define the earliest stage of stress that can be detected using DCIR.**

A number of algorithms were used in an attempt to identify a spectral stress signature. None of these were able to identify a stress condition in imagery taken three years before field checking. Very few fading trees were evident in this June, 1998 DCIR imagery. Three years between photography and ground-truthing is too long. It is necessary to analyze imagery of trees that are just beginning to show signs of stress, and those trees must be accurately marked on field images. Apparently, piñon show little sign of visible stress until black stain root disease or Ips bark beetles kill the tree. Needles quickly turn yellow and red, then fall from the tree. It would appear that trees looking chlorotic to the eye in the field are enhanced with DCIR images, but the enhancement does not produce "pre-visual" detection.

☐ **(4) Determine the potential effectiveness for using computer-aided analysis techniques to identify and map infested trees.**

Unsupervised classification techniques were used to identify piñon crowns by a process of elimination. Juniper crowns, piñon mortality, fading piñon crowns, as well as grass, bare soil, rock, small and large woody debris must be identified to classify piñon crowns for analysis. (See color Plate 4) Sage and shadows have some confusion in spectral

analysis. 'Cluster busting' techniques may be needed to identify some spectral classes accurately.

Juniper tree crowns in this high resolution imagery have some unique pixels which are diagnostic, and other more general spectral signatures. Juniper pixels were found to be somewhat sparse in a crown, and were identified by grouping algorithms. These were buffered with GIS raster image processing techniques, and were used to identify juniper crown masses. This reduced confusion with the more general piñon/conifer signature.

❑ **(5) Document appropriate automated computer processing techniques for mapping the location of mortality and stress.**

Rectification of raw imagery is not needed for image analysis, but is necessary for accurate mapping. DCIR taken at low heights above ground, such as these 1,500 and 2,000 foot examples, have large 'S'-shaped distortions that can be corrected with GPS locations collected in the field, or locations taken from a Digital Orthophoto Quadrangle. Six locations per image worked well, but four or five may be sufficient.

Computer file handling of original archive data is crucial. This issue is most important when the camera data is converted from the camera's native digital format to an archive file. A suitable file format is the .TIFF format, perhaps with LZW compression. LZW compression is suitable for 'lossless' archive, but requires software with a special license to read it. Histogram stretching should be done carefully by an analyst familiar with image processing issues, and should attempt to preserve the original histogram profile. Future image processing techniques may be able to make use of the original detail present in these files.

Very small resolution imagery (16cm or 6 inch) with high spectral texture may be effectively analyzed with unsupervised classification techniques. Supervised techniques were not effective, since uniform training polygons were not available in this highly textured landscape.

Smoothing with a 7x7 low pass filter is very effective, and makes the classification process faster, but is not recommended for preserving high levels of detail. Smoothing is effective for improving the appearance of a classification for presentation

Other spectral enhancement techniques have not proven to be of benefit in this study. Red minus green, and infrared minus red indices have not isolated piñon crowns uniquely, and NDVI appears to have strong piñon/grass conflict. Piñon values are intermediate in all of the index data sets and overlap with other vegetation. However, NDVI may be useful as an additional information band for statistical analysis. PCA analysis was of value in discriminating between landscape elements, but was not particularly helpful for determination of tree species. (See Plate 2)

Surprisingly, ratio analysis did not identify a stressed crown signature. This technique used three ratios, displayed with the three computer monitor color guns: (B)=IR/red ,

(G)= red/green, and (R)=red/IR. This highlights the differences in vegetation, crowns and soil background, but was not more effective than analyzing simple RGB images. This technique merits further study, but for one image, it obscured the detection of crown species. (See Plate 3)

Piñon and Juniper crowns were mapped using unsupervised classification techniques with GIS proximity analysis. Buffering of unique juniper pixels was effective in woodland areas. A high-pass filter, or edge-detection algorithm, was found to be effective in defining the perimeter of crowns and mortality centers.

5.2   Additional Results

Other observations and anecdotal results of DCIR imagery that were not directly studied include the following.

Computer file handling of original archive data is crucial. A suitable file format is the .TIFF format, perhaps with LZW compression. Histogram stretching should be done carefully by an analyst familiar with image processing issues, and should attempt to preserve the original histogram profile. This issue is most important when the camera data is converted from the camera's native digital format to an archive file.

There is some indication that cryptogam and lichen can be detected under favorable conditions. Small woody debris is also clear in the images, but shadowing and overstory vegetation may obscure it.

Soil and erosion conditions are much more visible in DCIR imagery, than CIR transparencies. Vegetation differences due to vehicle tracks are also clear.

Deer appear to be visible in the images from 450m (1,500 feet) above ground level.

Novel uses for this imagery may be: road condition surveys, off-road RV damage, recreation counts, large wildlife sampling, bird surveys, range condition surveys, and other uses where fine detail over a small area is needed. Reviewers indicated that there would be utility in the forestry, wildlife habitat, fuel assessments, grassland encroachment, vegetation assessment, erosion potential, hunting and recreation suitability, disease detection and other forest health issues.

The digital camera used for this project has been discontinued. Larger, faster, and more integrated systems have replaced it. This trend appears to be continuing.

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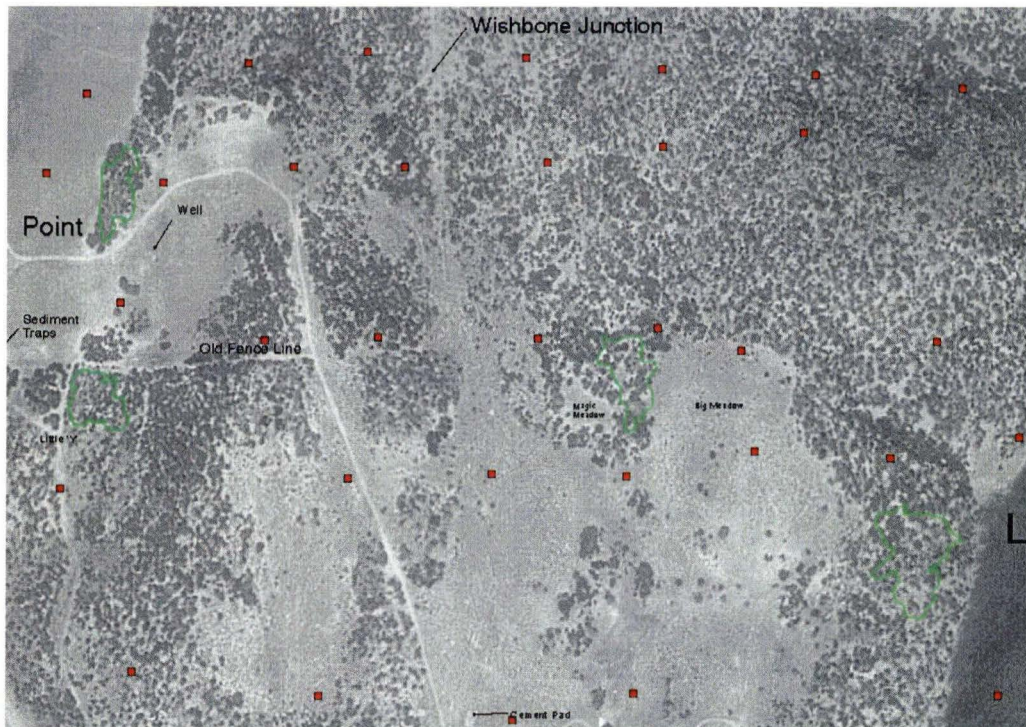
7   COLOR PLATES

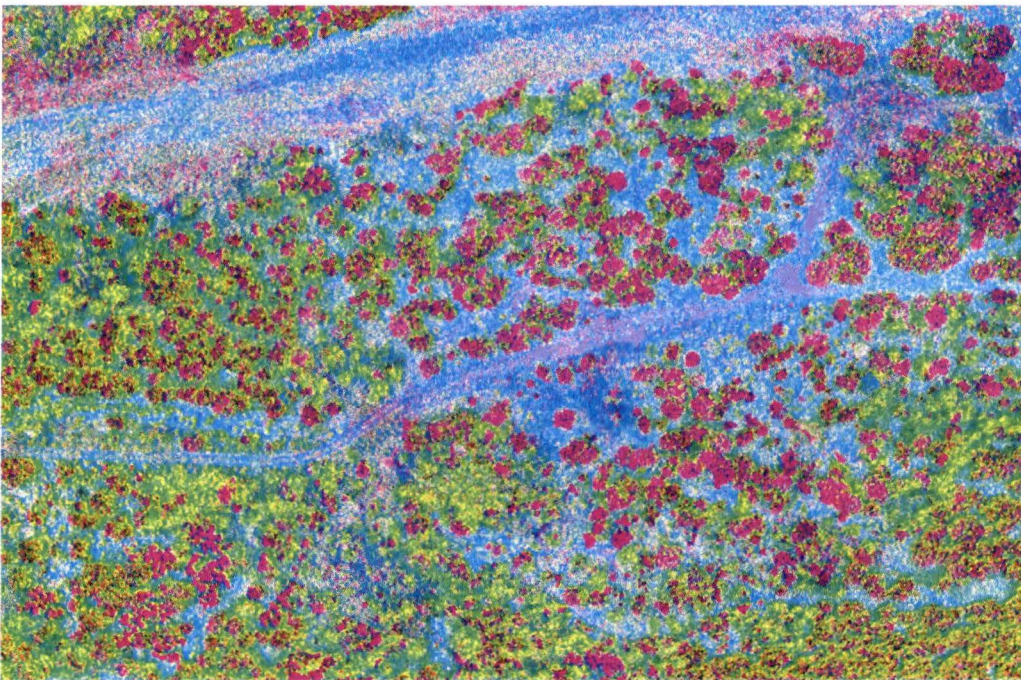**Plate 1**   Geographic Information System showing mortality and image centers.

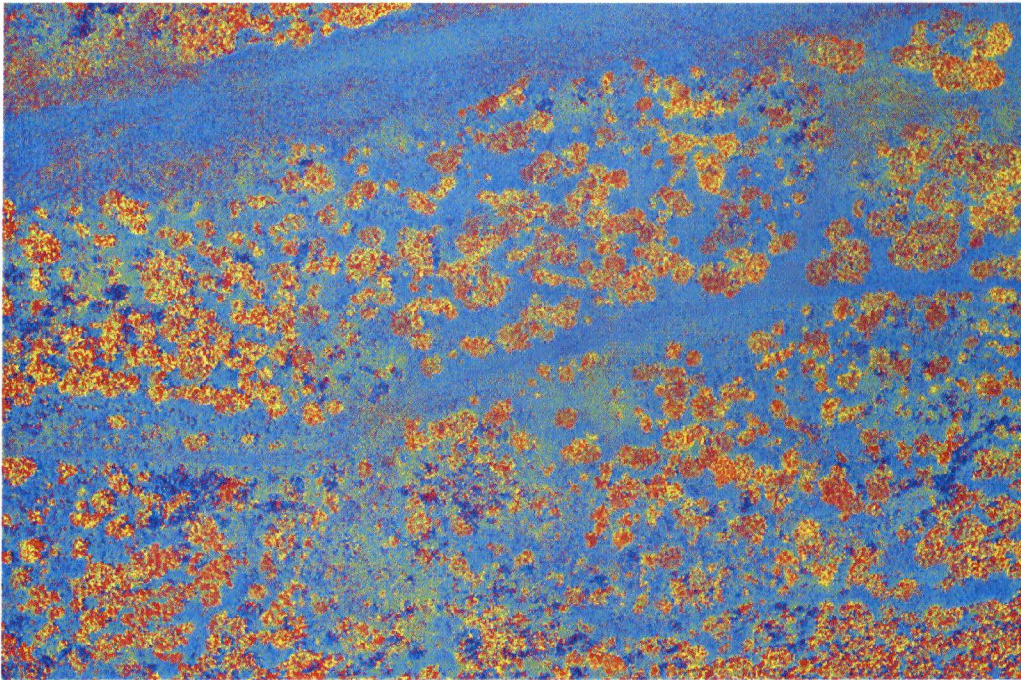**Plate 2**   Image produced with Principle Component Analysis

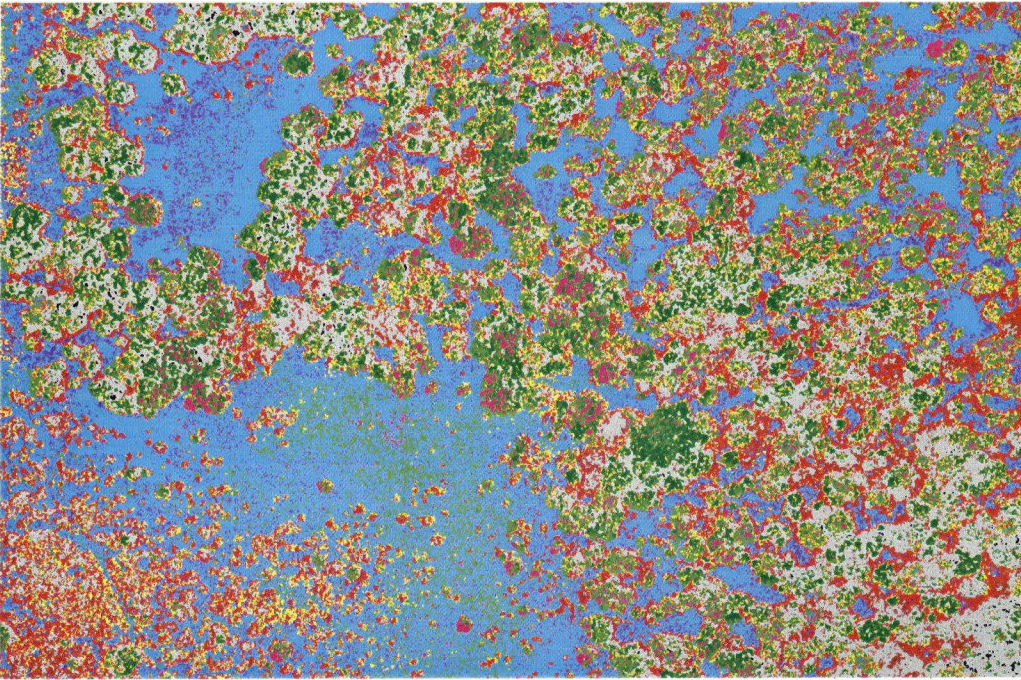**Plate 3** Image produced with three-band ratio analysis.

Plate 4 Classification with uncertain vegetation types highlighted with red.

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AUTHOR	Colorado State University	

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FOR MAPPING INSECT & DISEASE
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